

## **Inversion for Geoacoustic Model Parameters in Range-Dependent Shallow Water Environments**

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### **LONG TERM GOALS**

The ability to predict sound propagation in shallow water is limited by the knowledge of the geoacoustic properties of the ocean bottom. The long term goals of this research are: (1) to develop full field inversion methods for estimating parameters of geoacoustic models of the ocean bottom and the associated uncertainties in the model parameter values; and (2) to evaluate the performance of the geoacoustic inversion techniques for applications over a broad frequency band in range dependent shallow water environments. This work is set within the wider context of research to understand the interaction of sound with the ocean bottom and determine the critical geoacoustic parameters that affect sound transmission in shallow water.

### **OBJECTIVES**

The impact of variability in the sediment properties has been the focus of research in shallow water acoustics for several years. In SW06 a simple experiment based on a circular ship track around a vertical array was designed to study the azimuthal variation of geoacoustic model parameters. This report applies an inversion technique based on ray travel time of mid-frequency (1.1-4.5 kHz) sound signals to estimate geoacoustic profiles and study the heterogeneity of the sediment properties within the area of the circle. The approach is applied to circle data from two different sites that represented the two focal sites of the SW06 experiment: the MORAY site of 'outer shelf wedge' sediment that is clay-rich and stiff; and the SWAMI32 site where the outer shelf wedge sediment is overlain by a thin layer of medium sand. This work was done in collaboration with Dr. Y-M Jiang.

The recent ONR-sponsored research program in benchmarking geoacoustic inversion methods has demonstrated the maturity of present-day inversion methods against synthetic data for range-dependent shallow water environments (Chapman et al, 2003). A critical unresolved issue is the evaluation of the performance of the inversion methods for estimating geoacoustic profiles in real ocean environments. The experiments carried out in the ONR SW06 Experiment during August-September 2006 on the New Jersey continental shelf provided high quality data over a broad frequency band from 50 Hz to 20 kHz that can be used for evaluating and comparing the performance of several different techniques, including matched field inversion, reflection coefficient and bottom loss inversion, phase and group velocity dispersion and wavenumber extraction inversions. This report discusses initial performance

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comparisons of geoacoustic inversion methods that were used to estimate parameters of geoacoustic profiles in SW06.

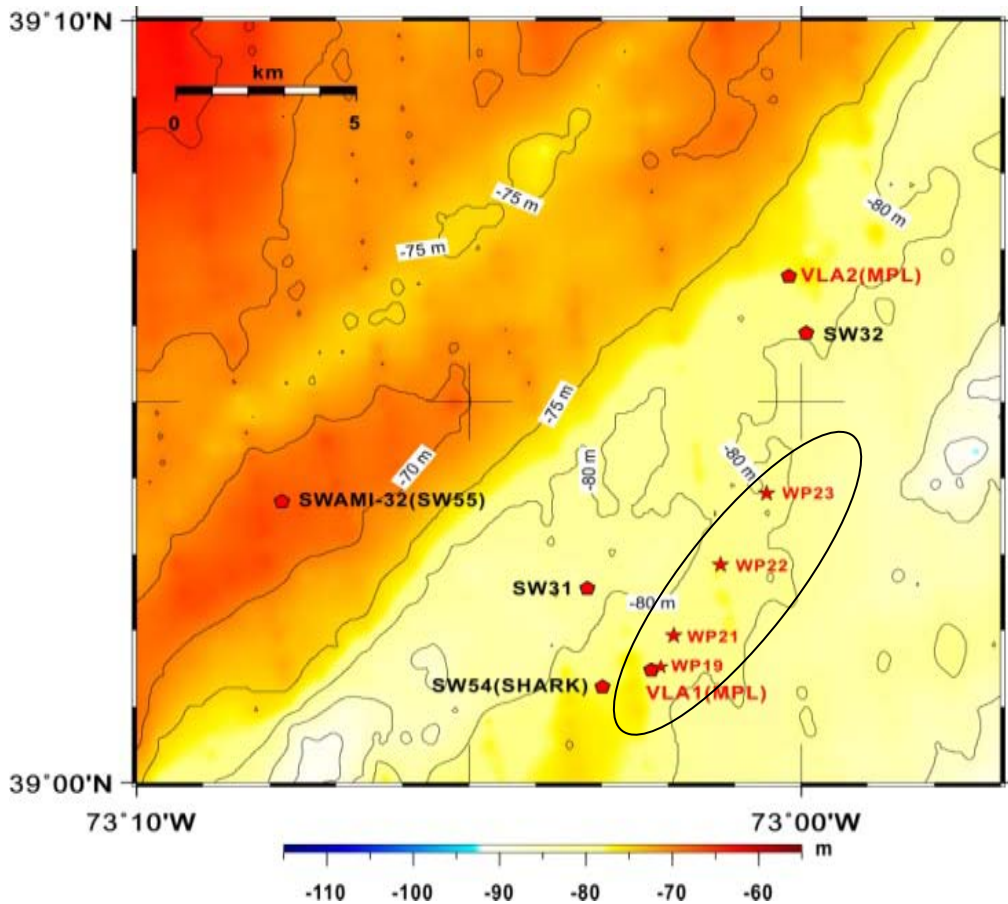
## APPROACH

The research makes use of data recorded on two different arrays: (1) the Marine Physical Laboratory (MPL) vertical line arrays in collaborative SW06 experiments with Drs. W. S. Hodgkiss and P. Gerstoft; and (2) the SWAMI L-shaped array deployed by Dr. David Knobles of the Applied Research Laboratories in Austin TX. These data provide the means to estimate geoacoustic model parameters over the band of frequencies of interest. Particularly, the frequency dependence of sound speed and attenuation in the sediment can be studied. The estimated models are based on Bayesian ray theory inversion of the mid frequency LFM sweep data.

**Description of the Experiments:** The shelf break location (Fig. 1) was specifically chosen to amplify the impact on geoacoustic inversion performance of uncertainties in the water sound speed profile due to internal waves, the shelf break front, a salinity/density and current that meanders near the shelf edge, and the frequent presence of warm-core eddies shed from the Gulf Stream. The MPL vertical array consisted of 16 hydrophones equally spaced at 3.75 m, with the bottom-most sensor 8.2 m above the sea floor. Water depth at the site was 79 m. The SWAMI array consisted of 32 hydrophones in an L-shaped configuration: ten phones vertically in the water and 20 phones stretched over ~200 m on the sea floor. Water depth at the site was 68 m. Mid-frequency sound signals over the band 1.5–4.5 kHz were generated by a separate sound source (an ITC 2015) that was towed by the R.V. Knorr at a depth of 25 m.

High resolution chirp sonar surveys carried out to map the bottom and sub-bottom structure in the region revealed well-resolved structure down to about 30 m, most prominently showing the ‘R’ reflector at about 20 m. This interface, which is pervasive in the region, was overlayed with alternating layers of sand and finer clay. In situ sediment probes were also deployed at locations around the MORAY site (Jie et al, 2008). The preliminary analysis of these data indicated a sound speed value of around 1620 m/s for the sea floor sediments near the MPL vertical array. However, the sea floor sediment type varied significantly over the region, most notably at sand ridges roughly parallel to the shelf break and a few kms north of the track at the SWAMI site.

**Mid frequency data:** Circular track experiments were carried out at very short ranges from the two different arrays. Previously we reported the results of the experiment at the MPL array site (Jiang et al., 2009). This report outlines the results of the short range circle experiment (~170 m; WP 55 in Figure 1) at the SWAMI32 array to determine high resolution structure of the geoacoustic model. The source was towed in the water at a depth of 25 m, and transmitted a 1-s LFM (linear frequency modulation) sweep signal over the mid-frequency band of 1.1-2.9 kHz. The match-filtered signal from the hydrophones of the horizontal component of the array showed a sub-bottom reflector at a relatively shallow depth, and a very weak signal from the deeper R-reflector. Variation in the signal strength of the shallow reflector for hydrophones along the array indicated significant sub-bottom heterogeneity in the vicinity.



*Figure 1. Location of the experiments on the New Jersey Shelf.*

## WORK COMPLETED

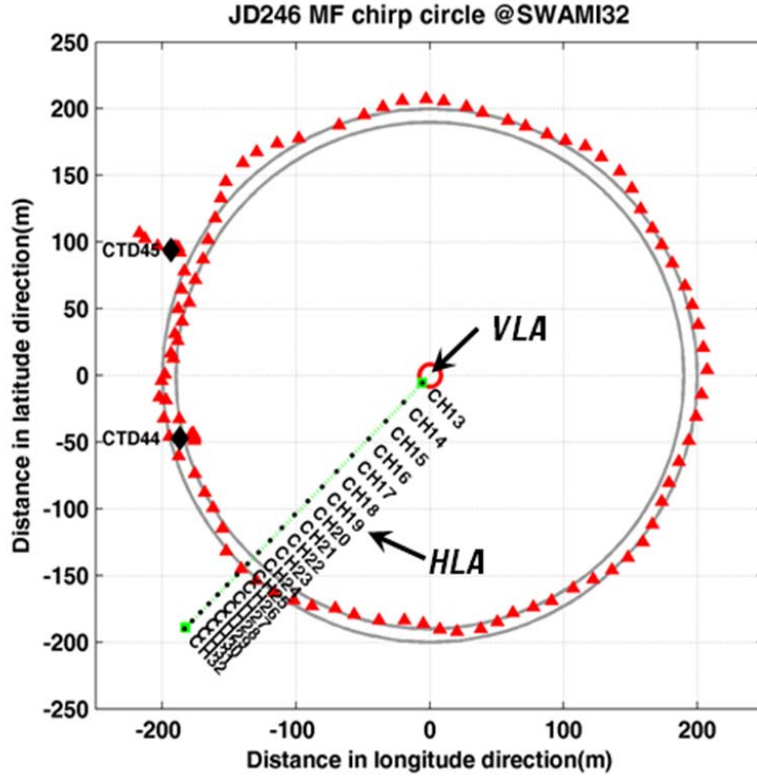
An inversion method was developed based on analysis of the ray amplitudes to characterize the structure and geoacoustic properties of the sediment material, and the inversion was applied successfully to the circle experiment data at the SWAMI32 site.

Initial work was done to collect and compare the results of different inversion techniques. Preliminary comparisons are shown here for inversions from some of the experiments at the MORAY site.

## RESULTS

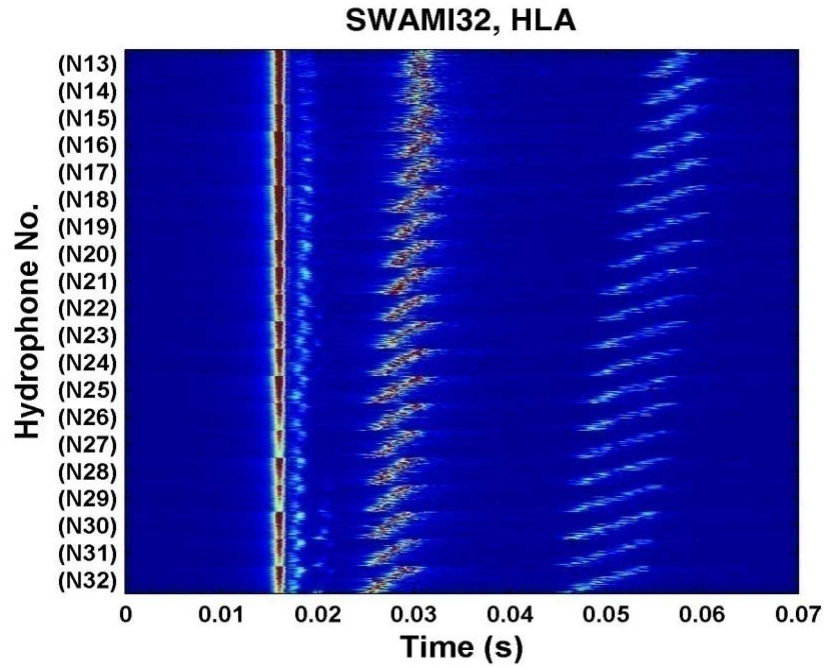
### *Mid Frequency inversions:*

The experimental geometry of the circle experiment is shown in Figure 2. Data were selected from the sound transmissions near the locations of the two CTDs (CTDs 44 and 45) shown in the figure. The matched filtered signals for one-minute averages of data for all the hydrophones along the horizontal array are shown in Figure 2 for one of the LFM transmissions. Only the shallow sub-bottom reflector is seen for this source position. The matched filtered signals for hydrophone 31 (about 200 m from the VLA) are shown in Figure 3 for a segment of about 4 minutes near the end of the circle. In this figure, each pulse is transmitted from a different source position along the track. The variability of the shallow sub-bottom reflector signal shows qualitatively the spatial scale of the heterogeneity in the sub-bottom structure at this site.

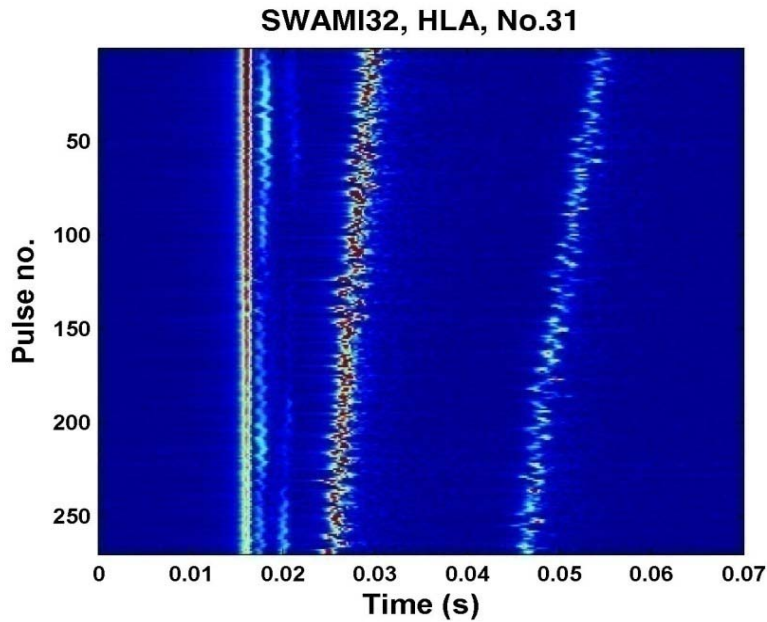


**Figure 2. Geometry of the horizontal and vertical SWAMI32 arrays and the circle track. Channels 13-32 are horizontal array channels. CTD 44 was taken at the start of the circle track, and CTD 45 was taken at the end of the track. The track duration around the circle was about 2 hours.**

A multi-step inversion method was developed to invert for the sound speed and thickness of the material in the first sub-bottom layer. It is believed that this layer is a thin layer of medium sand that overlies the outer wedge shelf sediment at the New Jersey shelf break. The first step in the inversion was to estimate the location of the array elements. This was done using the pulses at the beginning of the circle track that were close in time to the CTD measurement. For these pulses, the sound speed profile in the water was known, so a linear travel time inversion using direct path data recorded on the vertical array could provide the array geometry at the start of the circle. It was assumed that the VLA position did not change during the rest of the track. Subsequently, the source positions and the horizontal array positions could be determined in a second stage of the inversion. This stage inverted for the geometry and the sound speed to match travel time data recorded on the bottom VLA sensor and the horizontal array hydrophones. With the assumed geometry, the third stage used travel time difference data for the direct path and the sub-bottom reflector in a non-linear inversion to determine the sound speed and thickness of the sand layer. The results of the inversion are shown in Figure 5, which displays the marginal probability distributions of the parameters for two different source locations (see Figure 2). The estimated values of the sound speed are in excellent agreement with expected values for medium sand, and with estimated values reported by Knobles (Stott et al.) at the same site.

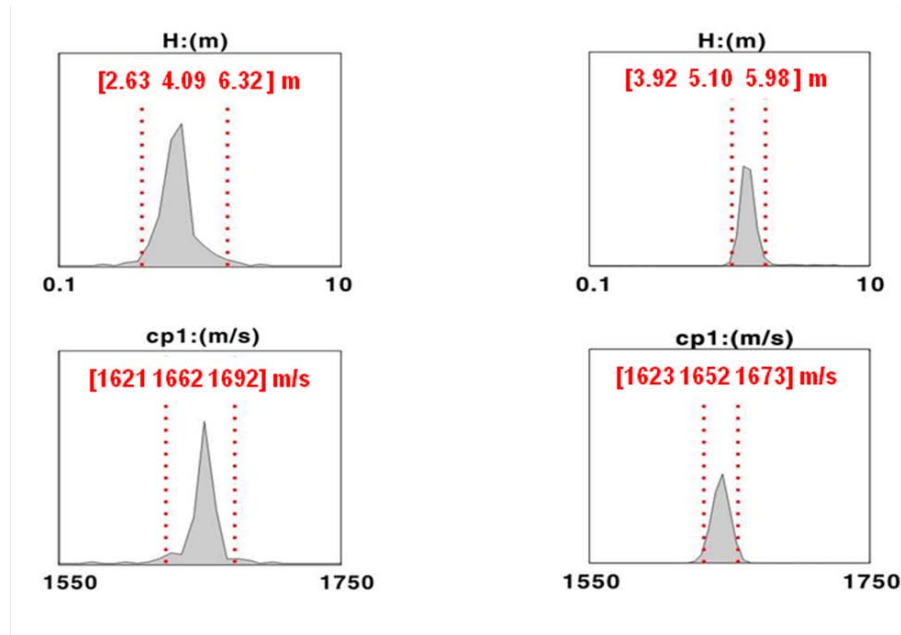


*Figure 3. Matched filtered signals from one pulse transmission received at all the hydrophones on the horizontal array. The display is aligned on the direct path signal at about 0.017s. The shallow sub-bottom reflector follows the direct path arrival, and a second sub-bottom signal is seen at hydrophones 30-32. The sea surface reflection is the strong signal that arrives at 0.026-0.03 s.*



*Figure 4. The matched filtered signals at hydrophone 31 near the end of the horizontal array for about 4 minutes near the end of the circle track. The variability of the two sub-bottom reflections is evident in the display.*

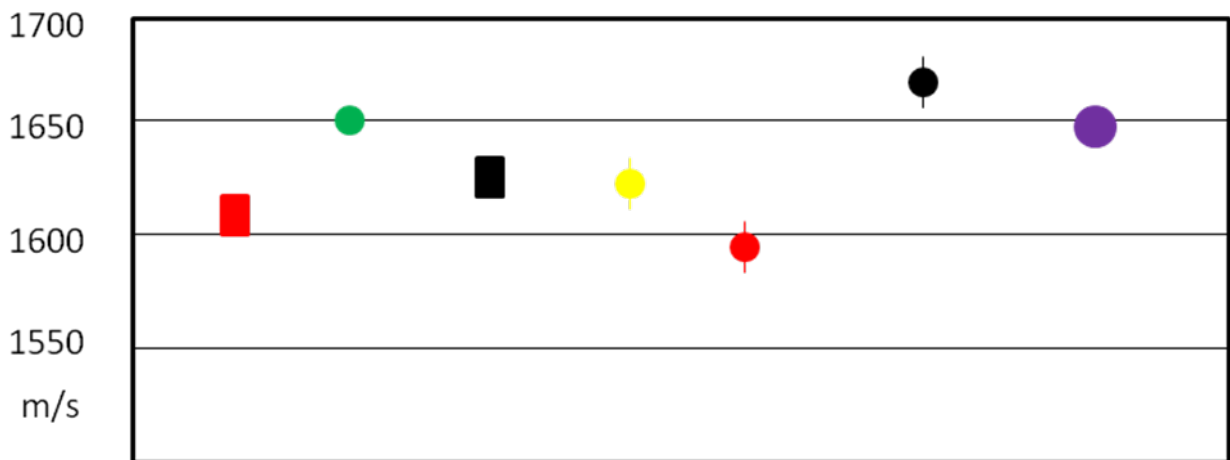




**Figure 5. Marginal probability distributions for the sound speed and layer Thickness of the sand layer at the SWAMI32 site.**

#### **Comparison of inversion techniques:**

Preliminary results of performance comparison of the inversion techniques that were applied in SW06 are shown in Figure 6 for the estimation of sound speed of the sea floor sediment in the vicinity of the MORAY site. The techniques included direct measurement using the SAMS (Seafloor Acoustic Measurement System) and inferred values from various inversion methods: matched field inversion; linear inversion of modal wavenumbers; modal dispersion analysis; and bottom reflection loss. Although there is a variation of about 50 m/s over the various estimates, it is not known at this stage how significant this is in making predictions of the acoustic field. The variation may well reflect the spatial heterogeneity in the sea floor sound speed over the region that was studied.



**Figure 6. Estimated values of sea floor sound speed from direct measurements (rectangles) and inferences from various inversion techniques (circles) applied to data from the MORAY site.**

## **IMPACT/APPLICATIONS/TRANSITIONS**

The assessment of performance of the inversion techniques will provide new information about the limitations and advantages of the different methods.

## **RELATED RESEARCH**

The data from the SW06 geoacoustic experiments are high quality data that can serve as benchmark standards for evaluating the performance of geoacoustic inversion methods. The research related to the analysis and interpretation of data from the geoacoustic experiments in SW06 is connected with the research projects of the following: W. S. Hodgkiss and P. Gerstoft (MPL, SCRIPPS); D. Knobles (ARL:UT); G.V. Frisk (Florida Atlantic); K. Becker (ARL Penn State); P. Dahl and D.J. Tang (APL UW); J. Miller (University of Rhode Island), J. Goff, U of Texas at Austin and J. Lynch (WHOI). The overall goal of this group is to characterize the geoacoustic environment and understand mechanisms of the interaction of sound with the ocean bottom. Comparison of the results from the different techniques will provide new understanding of the strengths and limitations of present day inversion techniques.

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